Microvibrations characterization of a 40 mNms Reaction Wheel with piezoelectric sensors for qualification

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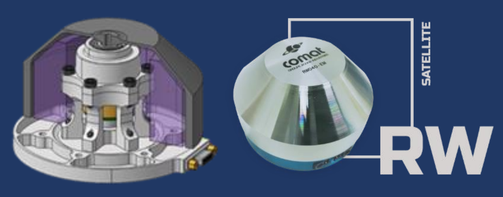


RW40 Characteristics

Torque

4mNm mean

Kinetic moment

40 mNms

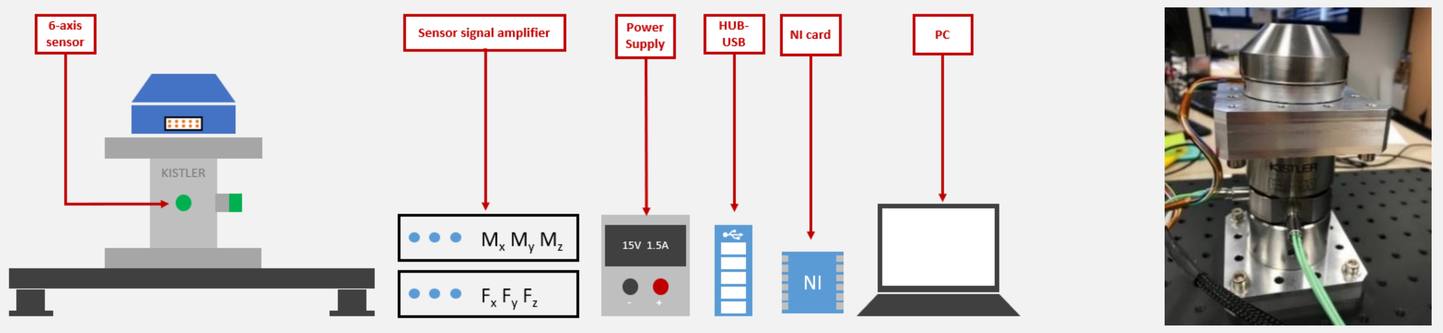
Accuracy

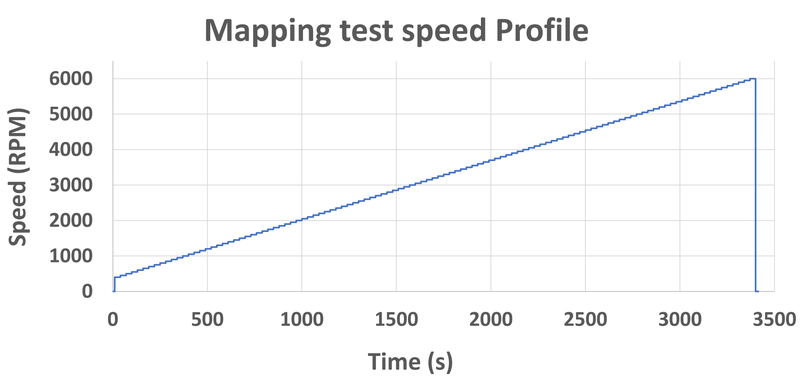
Down to 1 RPM

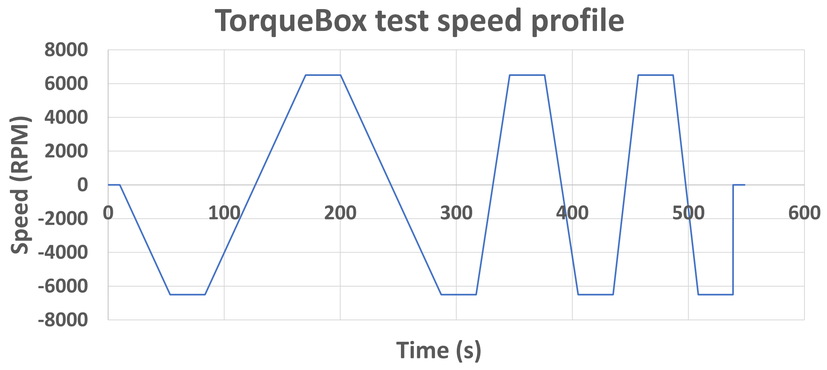
Objectives

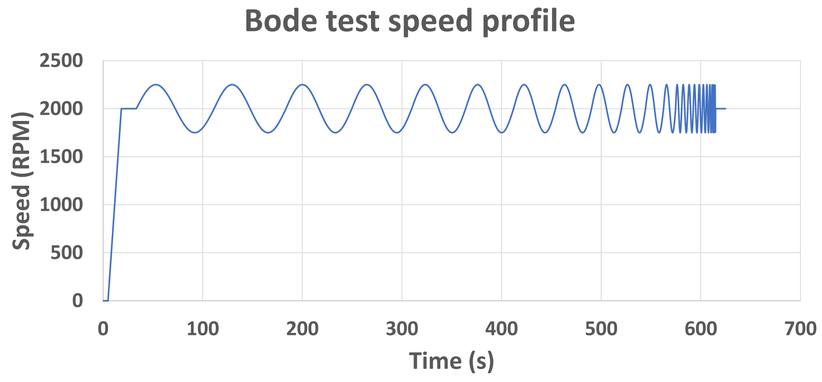
- To define a reliable, fast and simple method to characterize a 40 mNms reaction wheel
- To define a set of tests using a six-axis Kistler dynamometer measuring vibrations (forces and moments on 6 axes) in order to understand the mechanical behavior of the wheel, its health and configuration

Test bench









Output data

- Static and dynamic unbalances
- Wheel eigenmodes (rocking mode, overall mode, etc.)
- Tooling modes
- Monitoring of the vibration amplitude generated by the wheel
- Wheel defects
- Angular momentum
- Power consumption
- Speed setpoint tracking
- Cutoff frequency

Physical principles

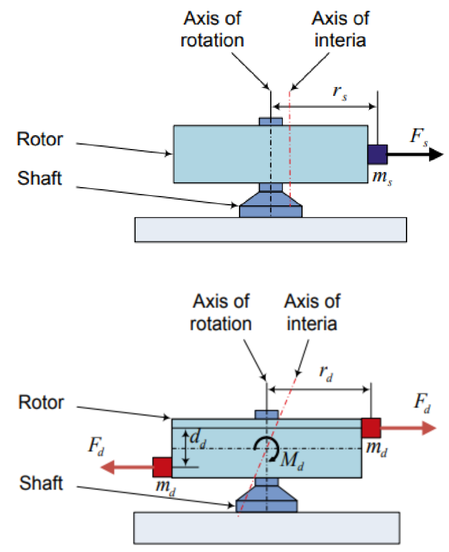
Static unbalance : $\boldsymbol{F_s} = m_s\, r_s\, \dot{\Omega}^2 = U_s\, \dot{\Omega}^2$ where F_s is in Newton, U_s is the static unbalance in kg.m and $\dot{\Omega}$ is the rotational speed in rad/s.

Dynamic unbalance : $\boldsymbol{M_d} = m_d\, r_d\, d_d\, \dot{\Omega}^2 = U_d\, \dot{\Omega}^2$ where M_d is the centripetal moment in Nm and U_d is the dynamic unbalance in kg.m².

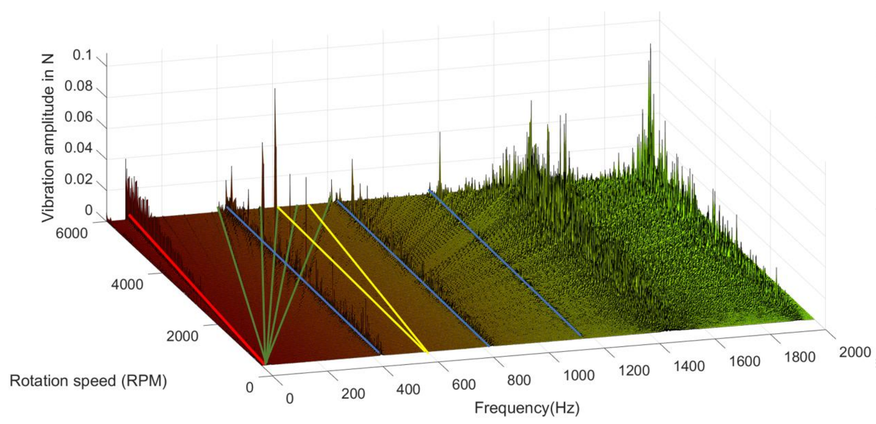
ISO balancing grade : $\boldsymbol{G} = e\, \dot{\Omega}$ and $\boldsymbol{e} = \frac{U_s}{m_r}$ where G is the residual unbalance in mm/s, e is the permissible specific unbalance in mm and m_r is the mass of the rotating part.

The rocking mode corresponds to two whirl modes (positive whirl mode and negative whirl mode), which have a natural frequency that depends on the rotation speed of the wheel :

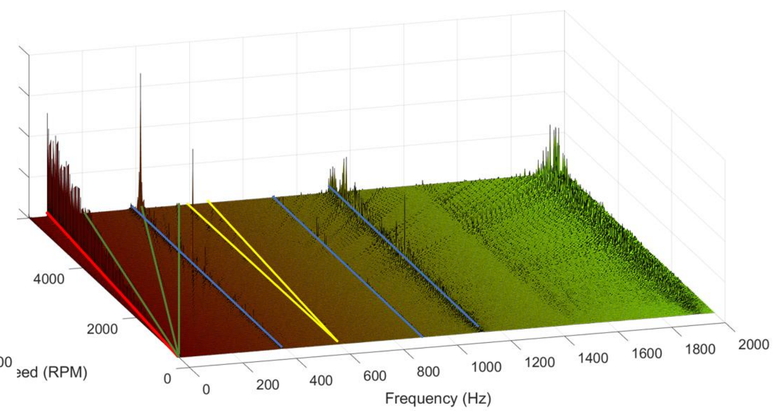
$\boldsymbol{\omega_{1,2}} = \pm \frac{\dot{\Omega} I_z}{2I_r} + \sqrt{\left(\frac{\dot{\Omega} I_z}{2I_r}\right)^2 + \frac{k_r\, d_2^2}{I_r}}$ where $\omega_{1,2}$ are the rotational natural frequencies in rad/s, k_r and k_a are the bearing radial and axial stifnesses respectively in N/m, I_r and I_z are the radial and axial inertias respectively in kg.m² and d_2 is the distance between the upper bearing and the center of gravity of the wheel.



Evolution of the micro-vibration forces on the x-axis



Evolution of the micro-vibration moments on the x-axis



To plot this, we perform an FFT between 0 and 2000 Hz for each speed step on the raw effort data. This is done on each axis of the wheel, giving a total of 6 waterfall plots. The results for this test are :

$\boldsymbol{U_s = 0.03}$ **g.mm**

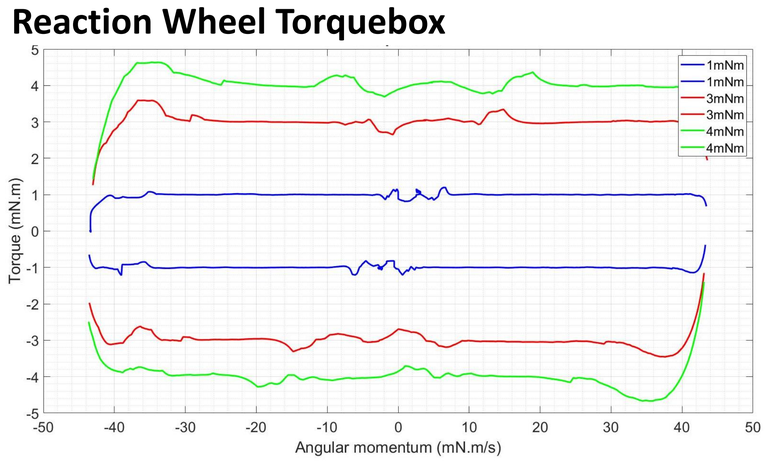
$\boldsymbol{U_d = 2.50}$ **g.mm²**

$\boldsymbol{G = 0.077}$ **mm/s**

In comparison with other wheels on the market, the theoretical static unbalance for a 40 mNms wheel is 0.15 g.mm and the dynamic unbalance is 7.0 g.mm². In addition, our wheel complies with ISO balancing grade G0.4, which is used for gyroscopes or disk-drives.

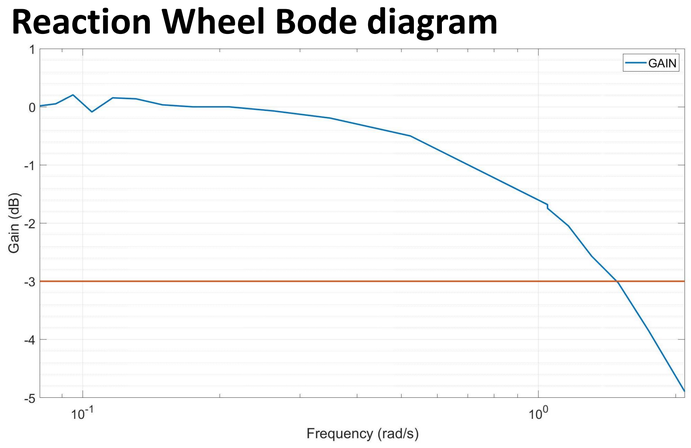
Static and dynamic unbalances — Wheel defects — Rocking mode — Tooling modes

Reaction Wheel Torquebox



The wheel provides a constant torque during acceleration and then reaches its nominal speed of 6000 RPM. The angular momentum increases with speed until it reaches its maximum of 40 mNms.

Reaction Wheel Bode diagram



ω_0=0.24

This cut-off frequency can be increased by adjusting the gains of the PI controller. However, care must be taken not to saturate the motor.